

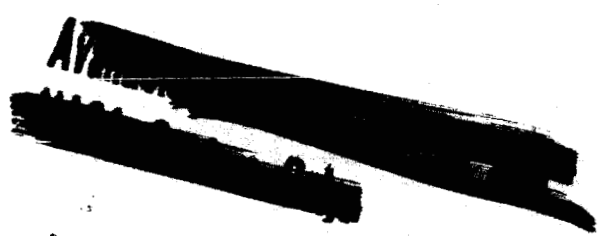
THE ORIGIN OF LUNAR SURFACE FEATURES

BY

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FACILITY FORM 802

N66-83565	(THRU)
(ACCESSION NUMBER)	None
32	(CODE)
(PAGES)	
TMX 56483	(CATEGORY)
(NASA CR OR TRX OR AD NUMBER)	



NOTE TO THE EDITOR

This article corresponds to an invited address presented to the Physics Club of Milwaukee on May 5, 1964, at the formal annual meeting of the Club. This Club is an affiliated society of the American Institute of Physics.

My present title is

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[REDACTED]

The last decade or so has witnessed a resurgence of interest in an area relatively neglected for a long time in favor of stellar studies by professional astronomers - the field of planetary astrophysics (as opposed to pure astrometry of the planets). This development has been stimulated in large part by the present availability of space vehicles which offer the possibility of unequivocal decision on questions for which the evidence obtained by the traditional means of the telescope is marginal at best. Simultaneously with this belated recognition by the astronomers of a lost child, the waif has been adopted by the geophysicists, who have extended their purview over the entire solar system. In fact, the situation has developed to the point where it is frequently difficult to assign the proper paternity (astronomical or geophysical) to a paper.

The present discussion is concerned with such an interdisciplinary problem - the relationship between surface features observed on the moon and the earth. The questions at issue are of obvious importance, in view of the imminence of the unmanned lunar landings of the Surveyor series of spacecraft and the manned mission of Apollo to the moon planned for this decade. No representation is made that the views expressed here are generally accepted.

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Scattered over the earth's surface are perhaps several dozen meteoritic craters or clusters of craters. Probably the best known of these is the Barringer (or Meteor) Crater in Arizona, a gaping hole in the earth over a kilometer across. To a distant observer on the ground, such a feature does not appear too conspicuous; it looks like one of the buttes of the Southwest. On approach, however, one notes that the ground slopes upward gradually to the top of the rim, where fragmented rock and huge boulders may be strewn. But beyond the rim, the ground slopes downward in a precipitous declivity into the pit of the crater. For the larger craters, the inner slope approaches a sheer cliff; to an observer on the brink, the view is that of a vast circular amphitheater below.

Invariably, the true bottom of the pit lies below the level of the surrounding terrain, although sediments, a lake, or vegetation may obscure this fact superficially. This circumstance alone rules out an explanation of these features as volcanic craters, which generally show the reverse condition (except for the relatively rare formation known as a caldera of collapse). For at least a century, the genesis of the craters was a matter of controversy among geologists, who were loath to accept an extraterrestrial origin. The first such craters noted historically were the cluster on the Estonian island of Oesel in the Baltic Sea, recorded in 1827. The Arizona crater was first brought to attention in 1891. Conclusive evidence of the origin of this crater in a meteorite impact was not provided until 1932, by D. M. Barringer; similar proof for the Oesel cluster was not forthcoming until 1937.

Unequivocal demonstration of meteoritic origin of a crater depends on elimination of possible geological processes as a cause, and the discovery of meteoritic material (usually iron or nickel) in association with the crater. On this basis, about fifteen craters or clusters of craters throughout the world have been authenticated as definitely of meteoritic origin. In addition to those certified on the rigid criterion noted, many more craters exist for which a meteoritic origin is suspected, on the basis of strong evidence. Meteoritic craters have been found in every continent (except Antarctica). They tend to appear in arid regions, where erosion and sedimentation are slow.

For meteorite craters which are both large and old, complicating factors enter the problem of identification. The geological forces of isostasy may operate to bring into equilibrium the disturbance in the earth's crust produced by the crater. Over a sufficiently long time, isostatic readjustment may cause the crater rim to descend because of the added weight on the rock underneath, while the floor of the crater is thrust upward simultaneously. This and the concomitant processes of erosion and sedimentation may destroy the crater as such. Only a circular ring of upturned rock in otherwise undisturbed strata may be left as the scar of the former crater. This description applies to a class of large formations known to geologists for a long time and recognized as caused by an explosion of unknown origin. They are called cryptoexplosive or cryptovolcanic features; the latter name implies a presumed volcanic source of the explosion.

Over the past few years, at least a dozen cryptoexplosive features have been identified as meteoritic in origin and not volcanic, as presumed. The diagnostic criteria used are the presence of coesite, stishovite, and shatter cones in the formations. Coesite and stishovite are dense forms of silica (the main constituent of common sand) which can be created only under high pressure and were discovered in laboratory experiments similar to those in which artificial diamonds were first produced. Shatter cones are conical fragments of rock with striations on the surface radiating from the apex. Laboratory experiments indicate that the pressures required to produce coesite, stishovite, and shatter cones are too high to be generated in a volcanic explosion.

The largest cryptoexplosive feature identified as meteoritic (through shatter cones) is the Vredefort Ring, in the Orange Free State of South Africa. Its diameter of about 50 km has been estimated to correspond to an energy release of roughly a million megatons of TNT. In contrast, an energy release of about 15 megatons (in the Mike shot in Operation Ivy) seems to be about the maximum reported by the Atomic Energy Commission for a hydrogen bomb.

It must be appreciated that a meteoritic crater is not formed by simple percussion of the impinging body, like the splash of a stone in mud. The bodies forming the craters are sufficiently large that they suffer only slight loss of speed and mass in traversing the atmosphere. Further, the velocities involved are so

high (above 11.2 km/sec), that the kinetic energy exceeds the explosive energy of an equal mass of a chemical explosive like TNT. When the meteorite strikes, shock waves are initiated which race back into the meteorite and ahead into the ground. Behind the shock waves, the material of the meteorite and the subjacent ground is transformed into a hot dense gas at extreme temperature and pressure, far above what any solid material can withstand. The subsequent explosive expansion of this gas produces the crater. For this reason, meteoritic craters are approximately circular, independently of the angle of fall of the meteorite. Further, it is rarely possible to recover more than a slight fraction, in the form of small fragments, of the original mass of the meteorite. That meteoritic impacts at astronomically possible velocities actually generate pressures and temperatures of explosive magnitude was demonstrated by Gilvarry and Hill in a calculation from first principles rather than on empirical grounds.¹

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The surface of the moon is dominated by an astonishing array of circular craters. Over 30,000 on the visible side of the moon have been measured with small telescopes, so that the actual number may run above the millions. Many (particularly in the highlands) show sharp features and a definite outline, while others (especially in the lowlands) appear damaged and even ruined. Since they were first

seen by Galileo in 1610 with his crude telescope, their origin is a question which has provoked speculation and controversy. Over the preceding century the view was prevalent that the craters were primarily of volcanic origin. In 1893, the geologist G. K. Gilbert demonstrated that this view was untenable, since the shape of the lunar crater does not conform to that observed for a terrestrial volcano, in general. In fact, the surface of the moon is distinguished by a relative lack of identifiable volcanic features.

The lunar craters show the salient characteristics of a meteoritic crater - the upraised rim with a gradual slope on the outer face and a steep one on the inner, and a floor depressed below the level of the neighboring terrain. For this basic reason, the consensus among most astronomers and many geologists today is that the vast majority of the lunar craters were formed by explosive impact of meteorites on the moon's surface, as proposed by Gilbert in 1893. Obviously no direct evidence has been observed for the meteoritic iron and nickel, the coesite, the stishovite, and the shatter cones which must be associated with the lunar craters, on the basis of the impact hypothesis. However, the argument can be strengthened by indirect means, based on the fact that the relative dimensions of a terrestrial meteoritic crater are characteristic. In 1933, L. J. Spencer of the British Museum noted that the depth of a terrestrial meteoritic crater is roughly one-sixth of the diameter, in general, and the same is true for craters formed

by military mines and high-explosive shells. This figure is about correct for the smallest lunar craters whose dimensions can be determined telescopically.

The argument was put in more sophisticated form by R. B. Baldwin² in 1949. He considered the dimensions of craters formed by artillery shells and bombs at low energy and accidental chemical explosions at high energy. He was able to construct a curve of diameter plotted against depth for these craters which runs smoothly into the corresponding curve for those lunar craters of his Class I (the youngest on the basis of the least appearance of superficial damage), as shown in Fig. 1. The bridge between the two types of crater was supplied by the terrestrial meteorite craters, which occupy an intermediate position. The curve displays a continuous progression through the three types of formation. Along it, the depth varies smoothly from one-sixth of the diameter for the small craters to about one-twentieth for the largest lunar craters, with a diameter approaching 150 km. The genetic relation implied by the Baldwin curve is one of the strongest arguments for the explosive origin of lunar craters in meteorite impacts.

Although Baldwin's correlation is rather convincing, it neglects entirely the most conspicuous features of the lunar surface - the dark areas apparent to the eye. The earliest lunar observers gave such a dark formation the Latin name "mare," on the presumption that it was a sea. These features certainly are not lunar seas

today. In view of the current belief that they never were seas, the term mare is generally regarded as a misnomer.

The maria can be divided into two broad classes. One class shows irregular borders. The other corresponding to the circular maria is characterized by a nearly circular outline and the presence of an encircling ring of mountains, with an escarpment on the inner wall and a gradual slope on the outer face. The floor lies below the level of the surrounding highlands. Therefore, a circular mare shows the main features of a meteorite crater. The archetype of the class is Mare Imbrium, which is about 1000 km in diameter. It is the dark patch appearing on the moon's disc toward the top (as viewed from the northern hemisphere). On the visible side of the moon, about six other circular maria are recognized.

Since the circular maria show the essential characteristics of a lunar crater, one must regard them as created by impact of a meteorite, although they are considerably larger than the average. However, some peculiarity must have been present in their mode of formation. In the first place, their depth as compared to their diameter is far below the usual, since the former is only about one two-hundredth of the latter. Secondly, their floors are covered, partially or completely, by some material whose dark and smooth appearance has generally been regarded as sufficient evidence to identify it as lava. Various sources of the lava have been proposed. Baldwin hypothesized that the lava was released from the

moon's interior through fissures rent by the meteorites on impact. In this connection, the author has pointed out that the existence of a dust layer over the entire surface of the moon, as revealed by eclipse observations and microwave measurements, largely vitiates the argument for the presence of lava.³

The first clue to a physical factor capable of affecting sharply the relative dimensions of an explosion crater at the time of formation was provided by the thermonuclear explosion Mike in Operation Ivy, conducted by the Atomic Energy Commission in 1952. The explosion took place on Elugelab, a small isle in the chain ringing the lagoon of Eniwetok Atoll in the Marshall Islands. According to the press of the time, Elugelab was completely blasted away to leave a crater 2 km in diameter and 60 m deep. On the basis of the Baldwin curve, the depth should have been about 300 m. Thus, the observed depth was far less than what one would expect for an explosion on land, and the difference obviously was caused by the presence of water of appreciable depth in the lagoon of Eniwetok. Since the time of the Mike shot, detailed data on the cratering effect of nuclear bombs in water have been released by the Atomic Energy Commission.

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The Mike explosion suggests that the former presence of water on the moon could have affected the relative dimensions of craters.

However, in invoking water or an atmosphere on the moon, one is faced with an apparent impasse. The molecules of every gas move at a high speed, determined by the temperature and increasing with it. In the upper layers of the atmosphere of a body like the earth, the temperature is far above that at ground level. As a consequence, some gas molecules at these heights may reach velocities exceeding the escape velocity fixed by the gravitational attraction of the parent body - the velocity a rocket must attain to escape. For this reason, every planet tends to lose its atmosphere with time, but only for a small one with its associated low escape velocity is the effect pronounced. Computations of the time of escape of atmospheric gases were first carried out by Sir James Jeans, and yielded the result that none of the lighter gases such as water vapor, nitrogen, or oxygen could have been retained for appreciable periods by the moon, because of its relatively small mass. In this connection, a significant time period is roughly a billion years, since the age of the earth as measured by radioactivity is about 4.5 billion years.

However, the computations of Jeans (and later of Baldwin)² were based on a tacit but determinative assumption. In the particular and important case of water, the procedure neglected the fact that loss of water vapor from an atmosphere can be replenished by evaporation from oceans. Because of the enormous number of molecules of water in the terrestrial oceans as compared to the number of molecules of any kind in the atmosphere, the crux of the

problem is to estimate reliably the extent of any oceans which once may have existed on the moon. In addition, Jeans' analysis requires a large correction factor first pointed out by L. Spitzer and justified further by the author.^{4,5}

During the past few decades, it has become increasingly clear that the terrestrial atmosphere and oceans are not residual from primordial antecedents present at the time of the earth's genesis. Rather, both the atmosphere and the oceans are of secondary origin, formed by exudation from the underlying earth through its surface. Both astronomical evidence, in the form of data on the cosmic abundances of chemical elements as compared to their terrestrial values, as well as purely geological evidence, conspire to yield this conclusion. Granted this premise, one must assume that any oceans on the moon were formed by leakage from its interior, analogously to the case of the earth. The total amounts of water exuded by the moon and earth can reasonably be expected to be simply proportional to the masses of the parent bodies. On the assumption that the time for effusion was short compared to the corresponding lifetime, one finds an average depth of about 2 km for the lunar oceans before their dissipation. The time required for escape of water vapor turns out to be of the order of three billion years,⁶ corresponding to the approximate diurnal range of 1000-2000° K for the temperature of the terrestrial escape layer,⁷ as one notes from Fig. 2. This estimate is about two-thirds of the earth's lifetime.

With the possibility of the presence of water on the moon suggested for a significant time, one is in a position to explain

the relative dimensions of the circular lunar maria. These maria are simply the oldest and largest of the lunar craters, formed at a remote time in the moon's past when the bombarding meteorites were larger than in later aeons. At this epoch, the lunar oceans were of appreciable depth, and the presence of the water resulted in the shallow depth compared to the diameter observed. From data for craters produced by nuclear explosions in water, one can construct a curve of diameter plotted against depth, which shows a smooth progression from the craters formed by the nuclear explosions into the craters corresponding to the circular maria, as shown by Fig. 1. A bridge between the two types of craters is provided by those of Class V on the moon, the oldest in point of damaged appearance. The depth varies smoothly along this curve from one-fortieth of the diameter for the craters from nuclear bombs to one two-hundredth for the maria. This curve is precisely analogous to Baldwin's curve, for the case where water of appreciable depth is present. One observes from Fig. 1 that the craters of Classes IV, III, and II of Baldwin, as he classifies them in order of decreasing age relative to the maria by apparent degree of damage, follow intermediate loci corresponding on this theory to the variation in water depth as a result of thermal dissipation of the hydrosphere. On the basis of the present hypothesis, it is the existence of the water that produces directly or indirectly the damaged appearance of the craters and maria, primarily.

Since these correlations conceivably could arise by a mechanism other than the effect of water (such as an adequate erosive process operative on an airless and waterless moon),⁸ one should look for confirmatory evidence of the hypothesized former presence of a lunar hydrosphere. Because of the relatively low surface gravity, small area available for watersheds, and thinness of the atmosphere (composed in later stages primarily of water vapor), erosion by flowing rivers and their tributaries should not have reached the significance observed on the earth. Thus, drainage patterns of the type (dendritic, pinnate, or other) characteristic of rivers should appear in the highlands but not prominently. Pickering⁹ has shown observationally that to some degree this actually seems to be the case. Many of the features in the highlands described by him consist of sinuous rills associated with craters, suggestive of the drainage pattern from a tarn, or mountain lake. Further, Shoemaker¹⁰ has noted the existence of several short lunar valleys with associated formations similar to deltas, which may be the relics of streams. One can point to other observational evidence for the pristine presence of a lunar hydrosphere.^{11,12} Telescopically, the relative lack of prominence of fluvial drainage patterns in the highlands can be understood on the basis of resolving power (1 km for the best photographs and 100 m for visual observation through a large telescope under the best seeing conditions).

On the hypothesis discussed here, the dark material in the maria represents sediments deposited from the lunar oceans in the course of their dissipation. The sediments are concentrated in the bottoms of the maria simply because these are the lowest regions, where the last oceanic water pocketed. On these considerations, a large part of the erosion evident for the lowland regions of the moon must have taken place under water. A significant amount may have been done by the silt carried by turbidity currents, which are known to play an important role in cutting submarine canyons on the earth. It is clear that the moon's surface may not always have been the dead wasteland that we see now - it may have passed through a youth as turbulent as that of the surface of the earth.

Two lunar maria have been photographed at close range and at high resolution by cameras in the Ranger series of space vehicles. The theory presented here is consistent with the photographs of the surface of Mare Nubium transmitted to the earth by Ranger VII. Thus, no deep dust exists on a mare, apparently.^{13,14} In addition, neither the furrows, cracks, and fissures appear (at a resolution less than 1 m) which one expects in lava sheets,¹⁵ nor the flow patterns one anticipates in this case,¹³ as is evident from the photographs published by the National Aeronautics and Space Administration. The photographs taken by Ranger VIII throw no significantly new light on this question, since they show that Mare Tranquillitatis is essentially similar to Mare Nubium in surface features.¹⁶ The pictures transmitted by Ranger IX are of Alphonsus, a crater

bordering on a mare and the highlands, and again are insufficient to settle the question at issue. It is more than probable that final adjudication cannot be made on the basis of photographs alone, and must await the results from the Surveyor and Apollo missions.

The dark color of the sedimentary deposits in the bottoms of the maria remains to be explained. Since only a small amount of organic carbon in a sediment is sufficient to yield a dark rock, the author has postulated that a primitive form of life once existed in the lunar oceans.^{6,12,17} All the requirements for the origin of life would once have been met on the moon, in view of the presumed existence for an extended time of an atmosphere and oceans. Their presence would reduce the large range of temperature observed at present between lunar day and night. In fact, at the time in question, the mean surface temperatures of the moon and earth must have been about the same. The time scale available is distinctly favorable to the possibility of life. The oldest known fossil plant is an alga discovered in rocks whose age measured by radioactivity indicates that life began on the earth within about two billion years of its origin, at most. This figure is a billion years less than the approximate time of escape calculated for lunar oceans. Thus, one can speculate that life originated on the moon through the same evolutionary processes required to explain life on the earth. The initial steps were the formation of fairly complex organic molecules through the action of solar ultraviolet

radiation and lightning discharges on the gases in a reducing atmosphere, as reproduced in the laboratory to some extent.

A positive clue exists that there once was life in the lunar oceans.^{6,12,17} As the oceans dissipated, the dark coloration in the basins of the circular maria tended to recede from the bases of the encircling mountains, as is evident in the pattern of light and dark color in the mare floors. It is characteristic of living matter to follow the retreat of its habitat in this manner. Other less definite clues exist.^{6,12,17}

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The present considerations have a direct bearing on the problem of the origin of tektites. These are glassy objects found in strewn fields of large extent over many regions of the globe. In general, they display signs of two periods of melting, although this characteristic is most marked in those (the australites) found in Australia. Since their chemical composition can be matched by terrestrial rocks, many origins for these bodies from the earth have been proposed over the years. A wide school of thought inclines to the belief that their provenance is terrestrial, in some manner.

An equally wide school of thought adheres to the view of H. H. Nininger that the tektites are fragments of rock fused initially by meteoritic impact on the moon and ejected from the lunar surface by the force of the explosion.^{6,18} This suggestion

is in accordance with the theoretical and experimental data on ejection velocities of fragments in hypervelocity impact.¹⁹ The second melting phase displayed by these objects then occurred during supersonic passage through the earth's atmosphere. Objections to the possibility of a swarm of bodies from the moon falling on the earth in a compact cluster seem to have been met in recent years on the basis of several possible modes of transit from the moon. Subject to the validity of one of these avenues of atmospheric entry, the theory of lunar origin yields properly two periods of fusion, the observed flow structure on the surface and the shape of these objects, as well as the distribution over the earth's surface. Further, the theory seems compatible with results on the cosmic-ray exposure ages of the tektites implying that their point of origin in the solar system can be no more remote than the moon.¹⁸

However, the chemical composition of most tektites is similar to that of sedimentary rocks, and the view that such rocks could not be present on the moon has precluded general acceptance of the idea of a lunar origin. This particular objection is met fully by the present theory, which implies the presence of lunar sedimentary rocks. Erosion would explain the existence of quartz particles in the lunar sediments, required to yield the lechatelierite (fused silica) found in tektites. Further, the salient anomalies of isotope abundances observed in these objects could be explained by the presence of residual water of low

concentration under the surfaces of the maria to recent times²⁰ (a hypothesis suggested by many investigators but not for the purpose in question here).

On the basis discussed, the present theory is sufficient to meet all the requirements for a lunar origin of tektites.¹⁸

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The foregoing interpretation of the evidence has been assailed vigorously by Goles, Urey, et al²¹ in a letter of comment on an article by the author,²² which prompted a strong rebuttal by Lear.²³ A major basis of their objections is that no evidence of a pristine hydrosphere on the moon exists in the form of observable river beds on the lunar surface or of sedimentary plains on the maria floors. This criticism is consistent with Urey's long championship of the idea that the floors of the maria are lava sheets created by the formerly molten residues of the impinging meteorites that created these features. However, he has recently espoused what amounts in many respects to a variant form of the theory presented here.²⁴

On this latest theory, Urey asserts that the comparatively smooth floors of the maria may be the beds of ancient temporary lakes, the water and in part the sedimentary content of which were transferred from the earth to the moon in a collisional process. This view obviously implies the presence of a pristine

atmosphere and hydrosphere for some time, sufficient in his own words to permit rainfall. In this connection, he cites the evidence adduced by Shoemaker¹⁰ for the former presence on the moon of streams of limited duration. Further, he claims that these bodies of water on the moon may have been inoculated with viable living matter or at least by organic compounds from the earth, in this initial process of transfer of terrestrial material to the lunar surface. On Gilvarry's theory, the source of the lunar water is effusion from the interior of the moon, in complete correspondence with the predicated case for the earth, and the hypothesized lunar life is indigenous.

The purpose of Urey's theory is to explain the presence of organic compounds in the carbonaceous chondrites. This class of meteorites is restricted in number (only a few dozen examples are known to exist). Urey purports to explain their presence on the earth by postulating that they arise as fragments thrown off the moon by collision with it of meteoritic bodies from the asteroidal belt. In this manner, he explains the presence of any organic matter of abiogenic or biogenic origin or any fossil vestiges of life that may be present in the carbonaceous chondrites as the terminal result of a sequence of events initiated by a transfer of

terrestrial antecedents through space to the moon. Thus, a second transfer process (from the moon in this case) is invoked to explain the terrestrial presence of matter stated to be derived ultimately from the earth itself.

As mechanisms for the hypothesized transfer of water, sedimentary rock, organic matter, and possibly living matter from our planet to its satellite, Urey calls upon the splashing effects into space from the terrestrial oceans involved either in escape of the moon from the earth or else capture of the moon by the earth. As he states, the first mechanism is highly unlikely. He notes that the second hypothesis probably would entail the presence of an additional body of lunar size in the process; this circumstance alone would strongly pejorate its probability. In any event, the over-all probability of the sequence of events postulated by Urey is a joint one, correspondingly lower than that of the two individual processes (transfer of matter from the earth to the moon and back again). Further, during the transit lasting at least a few days (and possibly a long period) from the earth to the moon, the liquid spray would possess insufficient gravity of its own and would lack the cohesive forces of a solid to prevent it from flashing off into the vacuum of space as

a vapor. Binary stars (such as β Lyrae) exist in which transfer of atmospheric gas from one body to the other is possible, but the primary masses involved in the system are of stellar and not planetary magnitude.

In the opinion of the author, the fragments spalled from the moon by meteoritic impact that are capable of reaching the earth in forms susceptible to recognition as extraterrestrial intruders are the tektites, primarily. Because of the high temperature they have been exposed to in the collision on the satellite, they should be essentially devoid of carbon from the maria, except possibly for traces of occluded gaseous compounds of this element. For the material thrown out of a lunar crater by meteoritic impact, the region of relatively high velocity in the flow field

necessary for escape is also the region of high temperature.¹ Thus, it would be very unlikely for the organic constituents of the carbonaceous chondrites to escape dissociation and vaporization if the source of these bodies were the lunar meteoritic impacts postulated by Urey. On this argument, the only fragments of the moon that could be found on earth in substantial numbers are the tektites, or fused silicates of some kind, in general. Independently, Gault has reached the same conclusion.²⁵

In any event, no organic material from the carbonaceous chondrites has been proved of biogenic origin, nor have any fossil forms of extraterrestrial life been identified unambiguously in these meteorites.¹² At least in the case of a fragment from one such meteorite (Orgueil), a hoax of the type of Piltdown man may have been perpetrated.²⁶

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It is clear from this discussion that the presence in former times of lunar oceans yields a direct explanation of the origin and relative dimensions of the lunar maria and of the nature of their floors. It is ironical that, on these views, the name mare is correct on the basis of provenance.

The correlation of dimensions of the lunar maria and craters has been extended by the author to the terrestrial ocean basins, on the hypothesis (made also by others) that these features were formed by explosive impact of large meteorites at a pristine

time far back in the Precambrian.^{27,28} It is necessary to assume that, at this epoch, the terrestrial hydrosphere covered the earth uniformly. Since this theory raises issues not entirely germane to the present discussion, it has not been pursued here.

Over the preceding ages, theories of the type considered here were amenable to verification only by indirect means, at the best. However, a current effort promises to change this situation. It is now a matter of national policy on the part of the United States, in competition with Russia, to analyze samples of lunar rock remotely by the unmanned vehicles of the Surveyor series in the near future, and to examine the lunar surface directly by men landed on the moon in the Apollo mission within the decade. Thus, the opportunity is at hand to observe directly the conclusive evidence for the impact theory of lunar craters - the meteoritic iron and nickel, the coesite, the stishovite, and the shatter cones. The former presence of lunar life inferred here may not be an abstract question shortly - it can be affirmed conclusively if biogenic carbon or fossils are found in the dark rocks of the maria. Hence, the present generation is living at a unique time in history when centuries of speculation may finally be ended with definitive answers.

The author wishes to thank Professor L. W. Friedrich, S. J., of Marquette University and Dr. C. W. Little of the Physics Club of Milwaukee for their invitation to give this address. The text

as printed is an adaptation in part (with changes to bring the material up to date) of an article²² published in and copyrighted by Saturday Review. Thanks are due the National Academy of Sciences - National Research Council for financial assistance.

REFERENCES

1. J. J. Gilvarry and J. E. Hill, "The Impact of Large Meteorites," Astrophys. J. 124, 610 (1956).
2. R. B. Baldwin, The Face of the Moon, University of Chicago Press, Chicago (1949).
3. J. J. Gilvarry, "The Nature of the Lunar Maria," Astrophys. J. 127, 751 (1958).
4. J. J. Gilvarry, "The Escape of Planetary Atmospheres. I. Escape Layer," Phys. Fluids 4, 2 (1961).
5. J. J. Gilvarry, "The Escape of Planetary Atmospheres. II. Lifetimes of Minor Constituents," Phys. Fluids 4, 8 (1961).
6. J. J. Gilvarry, "Origin and Nature of Lunar Surface Features," Nature 188, 886 (1960).
7. J. J. Gilvarry, "Physical Parameters of the Atmospheric Escape Layer," Nature 188, 804 (1960).
8. J. J. Gilvarry, "Nature of the Lunar Surface," Nature 180, 911 (1957).
9. W. H. Pickering, The Moon, Doubleday, Page and Co., New York (1903), p. 42.
10. E. M. Shoemaker, Private communication to H. C. Urey (reference 24).
11. J. J. Gilvarry, "Evidence for the Pristine Presence of a Lunar Hydrosphere," Publs. Astron. Soc. Pacific 76, 245 (1964).
12. J. J. Gilvarry, "The Possibility of a Primordial Lunar Life," in Current Aspects of Exobiology, G. Mamikunian and M. H. Briggs, eds., Pergamon Press, New York, 1965 (in press).

13. F. C. Hess, Quoted in The New York Times, Aug. 2, 1964, Sec. 1, p. 50.
14. E. M. Shoemaker, Quoted in The New York Times, Aug. 2, 1964, Sec. 1, p. 52.
15. G. P. Kuiper, Quoted in The New York Times, Aug. 2, 1964, Sec. 1, p. 52.
16. W. H. Pickering, Quoted in The New York Times, Feb. 21, 1965, Sec. 1. pp. 1, 65.
17. J. J. Gilvarry, "The Possibility of a Pristine Lunar Life," J. Theoretical Biology 6, 325 (1964).
18. J. J. Gilvarry, "The Lunar Origin of Tektites," Ann. New York Acad. Sci. (in press).
19. J. J. Gilvarry, "Effects of Loss of Lunar Mass by Meteoritic Impact," Icarus 3, 121 (1964).
20. J. J. Gilvarry, "The Lunar Origin of Tektites," Icarus (in press).
21. G. Goles, H. C. Urey, V. R. Murthy, W. Munk, H. W. Menard, A. E. J. Engel, and Tj. van Andel, "A Letter of Complaint and Protest From La Jolla," Saturday Review, April 7, 1962, p. 42.
22. J. J. Gilvarry, "How the Sky Drove the Land From the Bottom of the Sea," Saturday Review, Nov. 4, 1961, p. 53.
23. J. Lear, "When is a New Idea Fit to Print?" Saturday Review, April 7, 1962, p. 41.
24. H. C. Urey, "Meteorites and the Moon," Science 147, 1262 (1965).

25. D. Gault, Private communication to the author.
26. E. Anders, E. R. Du Fresne, R. Hayatsu, A. Cavaillé,
A. Du Fresne, and F. W. Fitch, "Contaminated Meteorite,"
Science 146, 1157 (1964).
27. J. J. Gilvarry, "The Origin of Ocean Basins and Continents,"
Nature 190, 1048 (1961).
28. J. J. Gilvarry, "Dimensional Correlation of Lunar Maria and
Terrestrial Ocean Basins," Nature 196, 975 (1962).

FIGURE LEGENDS

Fig. 1. Correlation of diameter D as a function of depth d for various classes of craters and the circular lunar maria. The solid curves correspond to fitted functions for craters on land and in water, applying to lunar craters of Classes I (including IH and IS) and V (including the lunar maria), respectively. The craters of Classes IH and IS are those of Class I lying in the highlands (hard rock) and the maria (soft rock), respectively. The correlation curves for lunar craters of Classes II, III, and IV are shown dashed. In general, points for only every tenth lunar crater in Classes IH and IS appear.

Fig. 2. Lifetimes of various constituents of the primitive lunar hydrosphere and atmosphere, as a function of assumed temperature in the escape layer at the top of the atmosphere. The curves for O_2 and N_2 are indistinguishable on the scale used.

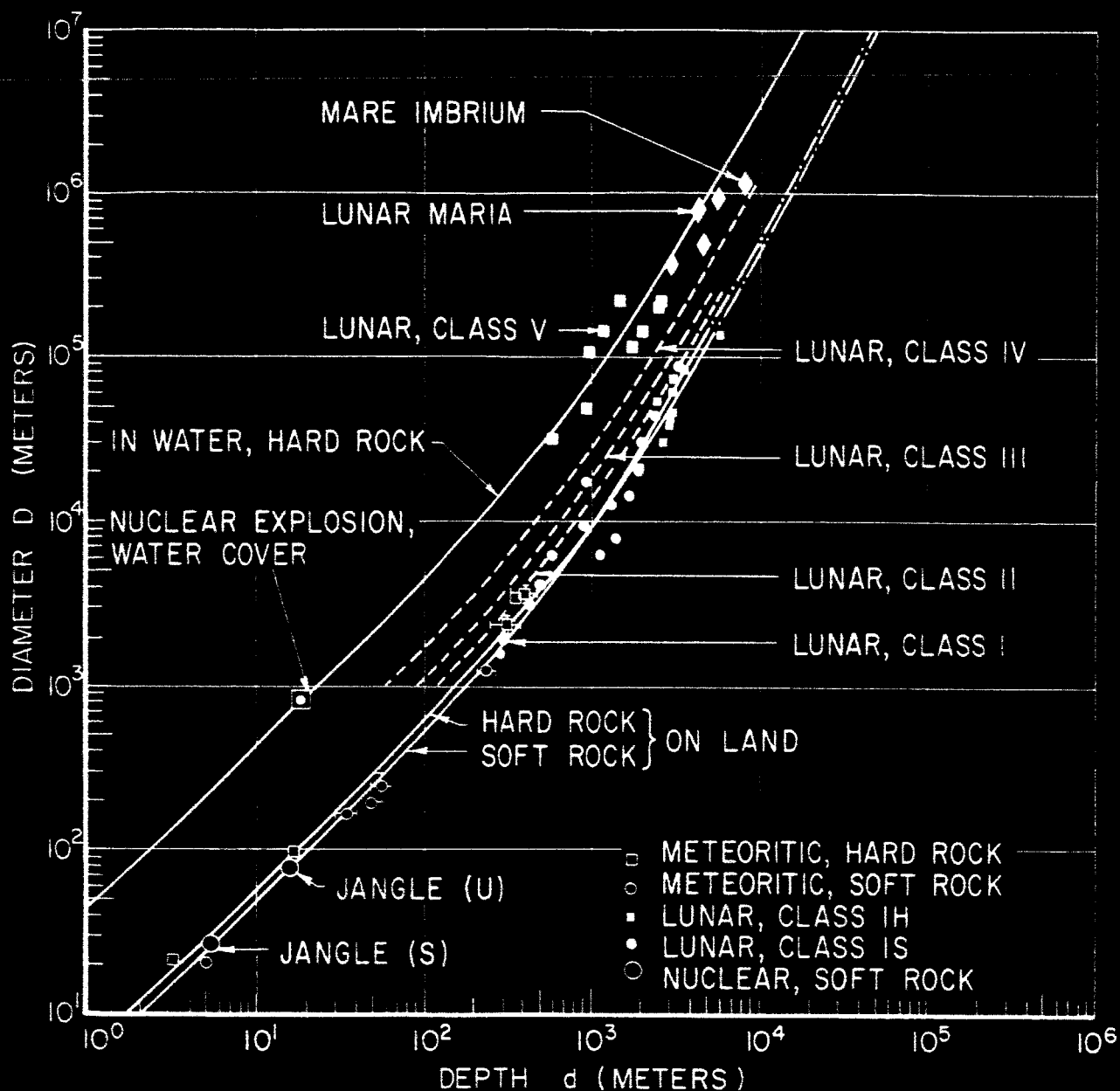


Figure 1.

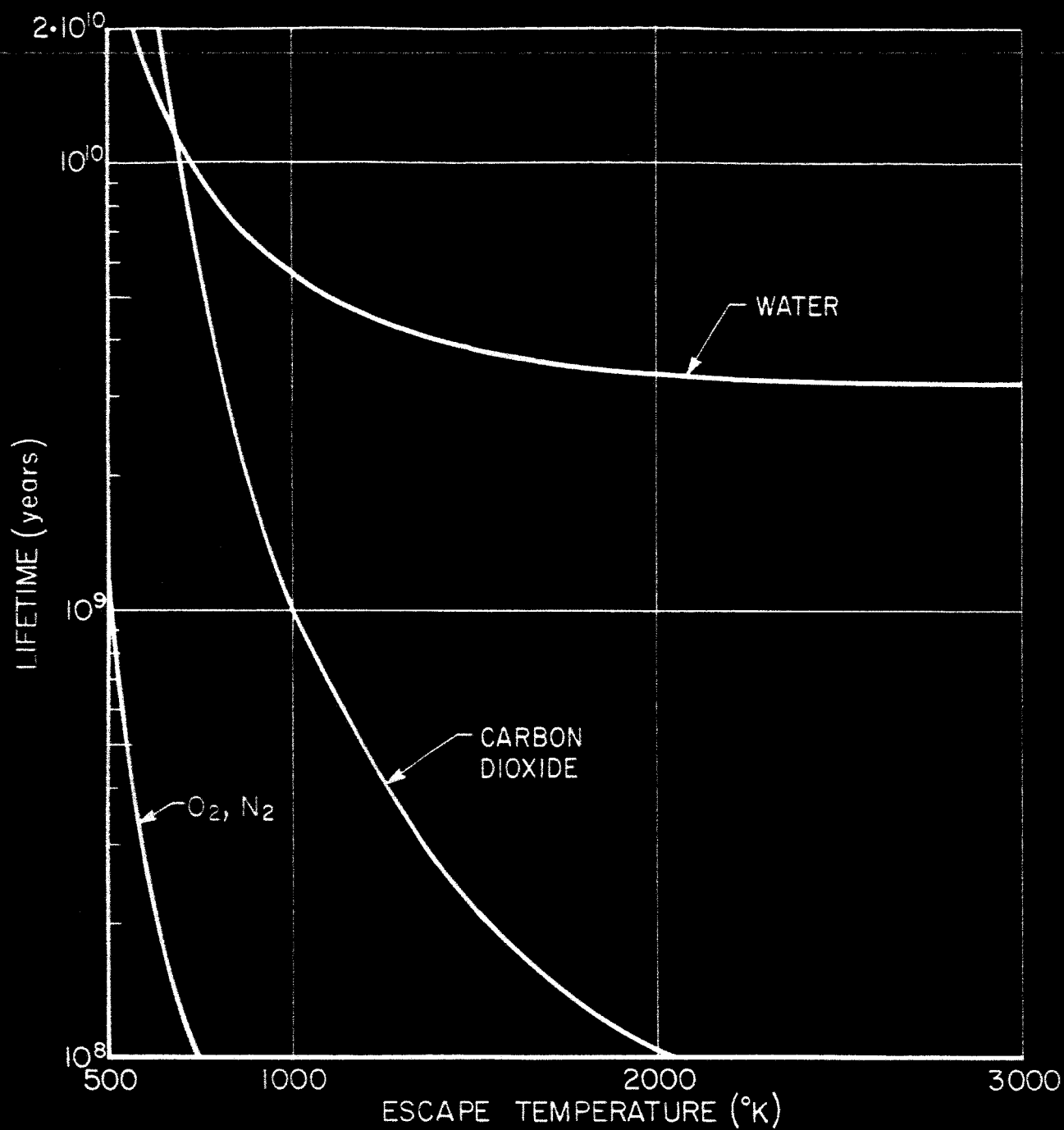


Figure 2.